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Revolutionizing Africa's Carbon Footprint through Innovative Technology Dissemination Strategies for Greenhouse Gas Emission Reduction: An MCDM Approach

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Abstract

In recent years, the urgency to tackle climate change and transition to sustainable energy sources has intensified. Africa, rich in Renewable Energy (RE) potential, is uniquely positioned to lead this global movement. However, the dissemination of innovative technologies for Greenhouse Gas (GHG) emission reduction is impeded by various challenges. This study identifies seven strategies through expert consultations and literature reviews and employs the Stepwise Weight Assessment Ratio Analysis (SWARA) within an Interval-Valued Intuitionistic Fuzzy (IVIF) framework to assess their relative importance. Key findings highlight that building robust RE infrastructure, leveraging incentives for adoption, fostering international knowledge partnerships, and enhancing capacity-building efforts are the most effective strategies. To strengthen the analysis, a comparative study with two other Multi-Criteria Decision-Making (MCDM) methods is conducted. The study recommends investing in solar and wind energy projects, offering subsidies and tax incentives to attract investment, and establishing a solid policy framework to encourage collaboration. Furthermore, enhancing vocational training and partnering with educational institutions is essential for developing a skilled workforce and ensuring long-term sustainability.

Keywords: Carbon footprint, Technology dissemination, Greenhouse gas, SWARA, IVIF.

1 | Introduction

Africa has immense potential for climate-smart initiatives, especially in the Renewable Energy (RE) sector [1]. The continent's vast and varied natural resources offer a solid base for sustainable energy development, which

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can meet local energy needs, reduce dependence on fossil fuels, and significantly contribute to global climate change mitigation efforts. However, several major challenges hinder the widespread adoption of Renewable Energy Technologies (RET) across Africa [2]. One significant issue is the inadequate infrastructure to support RE projects [3]. Many African countries have underdeveloped electricity grids that cannot efficiently transmit and distribute power from renewable sources.

Additionally, substantial initial capital investment is required for RE projects, creating a financial barrier for governments and private investors in financially constrained countries [4]. There is also a shortage of skilled human resources and technical expertise for RE systems due to insufficient training programs in these countries [5]. This skills gap hampers the scaling up of RE projects and the effective adoption of new technologies. Furthermore, ambiguous or bureaucratic policies often fail to support or incentivize RE investments, deterring investors and developers. Socio-economic factors also affect RE adoption, as many rural and underserved areas lack basic energy services [6].

Several studies have focused on the provision of different approaches or technologies for Greenhouse Gas (GHG) emissions mitigation. For instance, Smith et al. [7] analyzed barriers to GHG reduction in agriculture and discussed the links between mitigation, adaptation, and sustainable development, noting their impact on future emissions. However, they did not suggest innovative policies to overcome these barriers for effective agricultural GHG mitigation. Balafoutis et al. [8] highlighted the potential of Precision Agriculture Technologies (PATs) to reduce GHG emissions and their effects on economics and productivity. However, they did not stress the need for more research to quantify PATs' impact on GHG reductions, productivity, and income despite strong evidence supporting their role in climate change mitigation and improving efficiency. Bouman et al. [9] evaluated CO2 reduction strategies, identifying key approaches and quantifying their combined mitigation potential. However, they focused on a single strategy combination, achieving a 78% emission reduction using 3rd quartile values, while overlooking the possibility of numerous other combinations that could yield significant results. In Africa, Nwokolo et al. [10] explore the potential for reducing Africa's carbon footprint through the dissemination of innovative technologies aimed at GHG emission reduction. However, they do not establish a clear prioritization of these strategies. While existing studies largely concentrate on GHG reductions, there is a distinct need for targeted research that emphasizes the prioritization of innovative technology dissemination strategies for achieving GHG reductions in Africa. A comprehensive managerial approach is required to identify and prioritize these strategies, and Multi-Criteria Decision-Making (MCDM) techniques are ideal for this task [11–15].

The main contributions of this paper are as follows:

I. The authors obtained primary data by administering a Stepwise Weight Assessment Ratio Analysis (SWARA) questionnaire to experts with over 10 years of experience and a history of publishing on GHG emission reduction.

II. This study addresses a gap in research by evaluating innovative technology dissemination strategies for GHG emission reduction in Africa. The findings recommend that governments invest in solar and wind energy, offer subsidies and tax incentives, and create policies to enhance collaboration.

III. This study is novel as it utilizes an Interval-Valued Intuitionistic Fuzzy (IVIF) group decision model to evaluate innovative technology dissemination strategies for GHG emission reduction in Africa, distinguishing it from existing literature.

IV. The results of this study can aid African governments and policymakers in addressing challenges to effective GHG emission reduction by identifying the most appropriate strategies for real-world decision-making.

Following is the research objective. Evaluate and rank innovative technology dissemination strategies for reducing GHG emissions in Africa. The rest of the paper is organized as follows. Section 2 presents the literature review. Section 3 presents the methodology. Section 4 presents the application. Section 5 presents the comparative analysis. Section 6 presents the findings and discussion. Section 7 presents the managerial implications and Section 8 presents the conclusions and recommendations.

2 | Literature Review

2.1 | Approaches Related to Greenhouse Gas Emissions Reduction

Many studies have explored the reduction of GHG emissions across various contexts. Tian et al. [16] established a model for optimizing China's Chemical Fertilizers (CF) to balance GHG emissions, environmental protection, and crop yield but found that CF adjustments alone are insufficient. Ji et al. [17] reviewed Waste-based Geopolymer Materials (WGM) for wastewater treatment, detailing their forms, functions, and impact on reducing GHG emissions. Somantri and Surendro [18] studied how Computer Science Architecture (CSA) can help cut GHG emissions, exploring its impact on various domains and suggesting future research for a greener tech landscape. Björnsson and Ericsson [19] highlighted the potential for low GHG emissions in areas with ample wood fuels and efficient heat and power access. Tenhunen-Lunkka et al. [20] developed a model to project GHG emissions for the EU's mainly linear plastics value chain, assessing both 2018 and 2025 scenarios. Rony et al. [21] explored how alternative energy sources can support the UN SDGs and the challenges of implementing these solutions in maritime operations. Budihardjo et al. [22] selected approaches for cutting GHG emissions via sustainable municipal solid waste management in Indonesia. Lamb et al. [23] reviewed countries' progress in cutting emissions, focusing on the pace, depth, and sectors affected while analyzing changes in key GHG sources using both production and consumption data. Wei et al. [24] compiled energy-related GHG emission inventories for 167 cities worldwide, covering various sectors, and evaluated their near-, mid-, and long-term carbon mitigation targets for 2020 to 2050 at the city level. Gao et al. [25] reviewed the evidence on public health co-benefits to enhance understanding of the mitigation measures, underlying mechanisms, and associated uncertainties. Bocken et al. [26] introduced a new tool designed to help generate innovative product and process ideas aimed at achieving significant reductions in GHG emissions. Table 1 indicates the approaches used for GHG emissions reduction in Africa.

Table 1. Approaches for GHG emission reduction.

Ref.	Target	GDM	CA	Methods	Location
Tian et al. [16]	Optimization of chemical fertilizers consumption structure	No	No	Life cycle assessment	China
Ji et al. [17]	Solid waste-based geopolymer material application	No	No	Review	Global
Somantri and Surendro [18]	GHG emission reduction architecture	No	No	Review	Global
Björnsson and Ericsson [19]	Production of biojet fuels from wood	No	No	Life cycle assessment	Swedish
Tenhunen-Lunkka et al. [20]	GHG emission reduction potential	No	No	GHG emission estimation model	European Union
Rony et al. [21]	GHG emission reduction from maritime transport	No	No	Qualitative approach	Global
Budihardjo et al. [22]	GHG emission from municipal waste management	Yes	No	SWOT, QSPM	Indonesia
Lamb et al. [23]	Sustained GHG emissions reduction analysis	No	No	Global carbon project model	Six former Eastern Bloc countries
Wei et al. [24]	GHG emissions reduction progress and target	No	No	Inventory	167 cities worldwide
Gao et al. [25]	Public health co-benefits of GHG emissions reduction	No	No	Review	Global
Bocken et al. [26]	GHG emissions reduction options analysis	No	No	Eco-ideation tool	-
Our study	Innovative technology dissemination strategies for greenhouse gas emission reduction	Yes	Yes	IVIF-SWARA	Africa

Note: SWOT-strength weakness opportunity threat; QSPM- quantitative strategic planning matrix.

2.2 | MCDM-Related Studies on the Greenhouse Gas Emission Reduction

MCDM methods are efficient strategies used across various fields [27–31]. For instance, Karaşan et al. [32] proposed an approach to assess government strategies for reducing GHGs and promoting environmental sustainability. Dinçer et al. [33] applied distinct techniques to pinpoint key strategies for minimizing carbon emissions, identifying RE as the most vital factor. They recommended enhancing investments in RE through government incentives, such as low-interest loans and tax breaks. Narayanamoorthy et al. [34] used a new, hesitant MCDM approach for alternative fuel systems assessment based on various criteria. Ren and Lützen [35] introduced a fuzzy-based approach for choosing emission-reducing technologies in shipping, proving effective in identifying the most sustainable option despite uncertainties. Sakthivel et al. [36] introduced a method for choosing the best biodiesel blend for internal combustion engines, helping manufacturers and engineers meet fuel economy and emission standards. Balezentiene and Kusta [37] studied GHG emissions from grasslands using different mineral fertilizers at two distinct sites. Marzouk and Abdelakder [38] proposed a methodology to help construction decision-makers choose the most sustainable alternatives by analyzing four key objectives: construction time, lifecycle cost, environmental impact, and primary energy to build the Pareto front. Li et al. [39] assessed the progression and regional variations in RE development and utilization, focusing on their impact on carbon emission reduction. *Table 2* shows the use of MCDM approaches in studies related to GHG reduction.

Table 2. MCDM application on studies related to GHG reduction.

Source	Location	Focus	GDM	SA	Methodology
Karaşan et al. [32]	Türkiye	Governmental strategy assessment for GHG emission reduction	Yes	Yes	ISM, CM, IS
Dinçer et al. [33]	Europe	Carbon emission reduction problem analysis	Yes	Yes	CRITIC, MAIRCA
Narayanamoorthy et al. [34]	-	Alternative choice for GHG emission control	Yes	Yes	DEMATEL, COPRAS
Ren and Lützen [35]	-	Technology selection for emission reduction from shipping	Yes	Yes	AHP, VIKOR
Sakthivel et al. [36]	-	Optimum fish oil fuel selection for GHG emission	Yes	No	ANP, TOPSIS
Balezentiene and Kusta [37]	Lithuania	GHG emission reduction strategy analysis	Yes	No	ARAS
Marzouk and Abdelakder [38]	-	Environment emission minimization	Yes	No	WSM, COPRAS, TOPSIS, PROMETHEE II
Li et al. [39]	China	Development and utilization of renewable energy based on carbon emission reduction	Yes	No	ANP
Our study	Africa	Innovative technology dissemination strategies for greenhouse gas emission reduction	Yes	Yes	IVIF-SWARA

Note: Analytic Hierarchy Process (AHP); Analytic Network Process (ANP); Complex Proportional Assessment (COPRAS); Criteria Importance Through Intercriteria Correlation (CRITIC); Cognitive Mapping (CM); Decision-Making Trial and Evaluation Laboratory (DEMATEL); Inference Systems (IS); Interpretative Structural Modeling (ISM); Multi-Attributive Ideal-Real Comparative Analysis (MAIRCA); Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE); Technique for Order Preference by Similarity to Ideal Solution (TOPSIS); - Vlsekriterijumska Optimizacija I KOmpromisno Resenje (VIKOR); Weighted Sum Method (WSM).

2.3 | Research Gaps

This study addresses a specific challenge in Africa: the evaluation and ranking of innovative technology dissemination strategies aimed at reducing GHG emissions. It uniquely examines these strategies from an

MCDM perspective, a viewpoint not previously explored (refer to *Table 2*). Additionally, the research employs an IVIF group decision-making model for assessment and ranking, marking its first application in this context (see *Table 1* and *Table 2*). The study also aims to identify the most appropriate strategies, representing a novel investigation that has yet to be undertaken (see *Table 1* and *Table 2*).

3 | Methodology

In decision-making scenarios involving multiple criteria, the objective is typically to select the optimal option from a range of alternatives [40–48]. However, traditional Fuzzy Set (FS) theory faces limitations when dealing with the complexities and uncertainties inherent in such situations [49]. To overcome these challenges, researchers have adopted Intuitionistic Fuzzy Sets (IFSs), which are powerful tools for managing uncertainty in MCDM problems [50–55]. IFSs are particularly effective in capturing imprecise or less-than-reliable judgments by incorporating not only affirmation and negation but also hesitation through the use of membership functions [56–58]. A significant issue in IFS theory is expanding the definition and operations of IFS [59–62]. To address this, Atanassov and Gargov [50] introduced the concept of Interval-Valued Intuitionistic Fuzzy Sets (IVIFS), extending the traditional IFS model. The IVIFS algorithm provides notable advantages over IFS, particularly in dealing with complexity and vague information. By employing IVIFS, uncertainty can be more effectively represented, and expert opinions can be integrated into the decision-making process.

Criteria weighting methods, such as Level Based Weight Assessment (LBWA) and FUll Consistency Method (FUCOM), rely on decision-makers judgments [63–66]. While LBWA offers flexibility [67], FUCOM has shown better results than the Best-Worst Method (BWM) but lacks extensive validation [68], [69]. BWM is quicker due to fewer pairwise comparisons but can be less effective for complex models [70]. The SWARA method simplifies computations and identifies subjective weights effectively [48]. Despite its successes, there is a gap in applying SWARA within an IVIF framework for evaluating innovative technology dissemination strategies to reduce GHG emissions in Africa, which this study aims to address.

In our study, the methodology adopted comprised two stages: At first, data was collected via experts' opinions and literature review. Then, seven strategies to reduce GHG emissions in Africa were assessed via the application of the SWARA approach under the IVIF environment. The flowchart of our study approach is shown in *Fig. 1*.

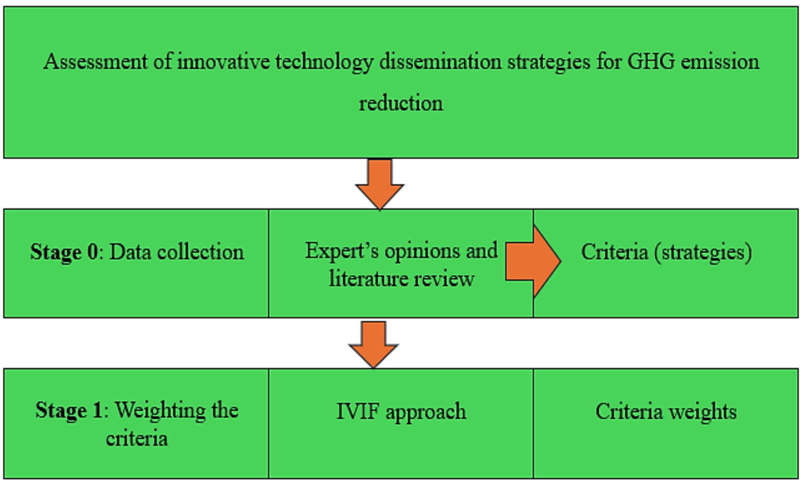

Fig. 1. Flowchart of the study.

Step 1. A group of experts (Es) is assembled, and the significance of each member is assessed. The group consists of academicians and industry experts who will be responsible for rating the strategies.

Step 2. The criteria are sorted by their relative importance. Each expert uses their expertise and judgments to arrange them in order of importance, using linguistic evaluation and a fuzzy rating derived from *Table A1*.

Step 3. The aggregated expert assessments are constructed. Once the significance scores of all experts have been calculated, the IVIFHG operator is applied for the aggregating score.

Step 4. The score value is computed.

Step 5. Each criterion's average relative weight (S_j) is found by establishing the weight of criterion j with criterion (j-1) beginning from the second criterion. The most important criterion, j, in proportion to the antecedent criterion (j-1), is first positioned, and the least important criterion, j, is placed last.

Step 6. Find the (k_j) coefficient. The coefficient is calculated using *Eq. (1)*.

$$k_j = \begin{cases} 1, & j = 1, \\ S_{j+1,} & j > 1. \end{cases} \tag{1}$$

Step 7. Determine the weights (q_j).

$$q_j = \begin{cases} 1, & j = 1, \\ \dfrac{q_{j-1}}{k_j}, & j > 1. \end{cases} \tag{2}$$

Step 8. The assessment criteria's comparative weights are determined and shown in *Eq. (3)*.

$$w_j = \frac{q_j}{\sum_{j=1}^{n} q_j}. \tag{3}$$

where w_j and n are the weight of the jth criterion and criteria numbers, respectively.

4 | Application

In our study, seven alternatives characterizing the innovative technology dissemination strategies for GHG emission reduction are presented in *Table A3*. These strategies are first obtained through existing studies. Then, expert judgment has been applied to validate these strategies since it is vital in decision-making and problem-solving, but the number of experts should be limited to avoid skewed results, with studies suggesting no more than seven participants [71]. In our study, four experienced professionals, detailed in *Table A2*, were selected based on criteria such as a strong publication record on GHG emission reduction and at least 10 years of either industry and academic experience. After inviting six qualified experts, four agreed to participate. These experts, equally valued, include two academics and two industry professionals, all holding at least a bachelor's degree and over a decade of experience.

4.1 | Prioritizing the Strategies

Step 1. Experts first evaluate the criteria from *Table A1*, which are then converted into IVIF numbers. *Table 3* presents these assessments.

Table 3. ssessment of criteria.

Criteria	E-1	E-2	E-3	E-4
S1	VH	VH	H	AH
S2	AH	AH	VH	AH
S3	EE	EE	EE	MH
S4	VH	H	H	H
S5	MH	MH	EE	MH
S6	H	MH	H	MH
S7	ML	EE	L	AH

Note: E –expert.

Step 2. Expert opinions on the criteria are aggregated, assuming equal expert weights (*Table 4*).

Table 4. Aggregated evaluations of criteria.

Criteria	μ_L	μ_U	v_L	v_U
S1	0.5990	0.6991	0.1507	0.3009
S2	0.6371	0.7372	0.1128	0.2628
S3	0.5000	0.5233	0.4467	0.4767
S4	0.5621	0.6622	0.1878	0.3378
S5	0.5000	0.5733	0.3223	0.4267
S6	0.5244	0.6245	0.2254	0.3755
S7	0.3570	0.4787	0.4359	0.5213

Steps 3. Each criterion is scored and ranked in order of importance. Then, the IVIF-SWARA method is used from *Step 3* through *Step 8*, with details indicated in *Table 5*. An illustration of how criteria (S1) is calculated is shown below.

Step 4. Score of criteria (S1) = 0.5* (0.5990+0.6991-0.1507+-0.3009) = 0.4225.

Step 5. s_j (S1) = score of S2 - score of S1 = 0.4994 - 0.4232 = 0.0762.

Step 6. k_j (S1) = 1 + 0.0762 = 1.0762.

Step 7. q_j (S1) = $1/k_j$ (S1) = 1/1.076 = 0.929.

Table 5. Results of IVIF-SWARA.

Steps	4	5	6	7
Criteria	Score	s_j	k_j	q_j
S2	0.499		1	1
S1	0.423	0.076	1.076	0.929
S4	0.349	0.074	1.074	0.865
S6	0.274	0.075	1.075	0.805
S5	0.162	0.112	1.112	0.724
S3	0.050	0.112	1.112	0.651
S7	-0.061	0.111	1.111	0.586

Step 8. *Fig. 2* shows the significance of each criterion based on the final weights obtained by normalizing the recomputed weights using *Eq. (3)*.

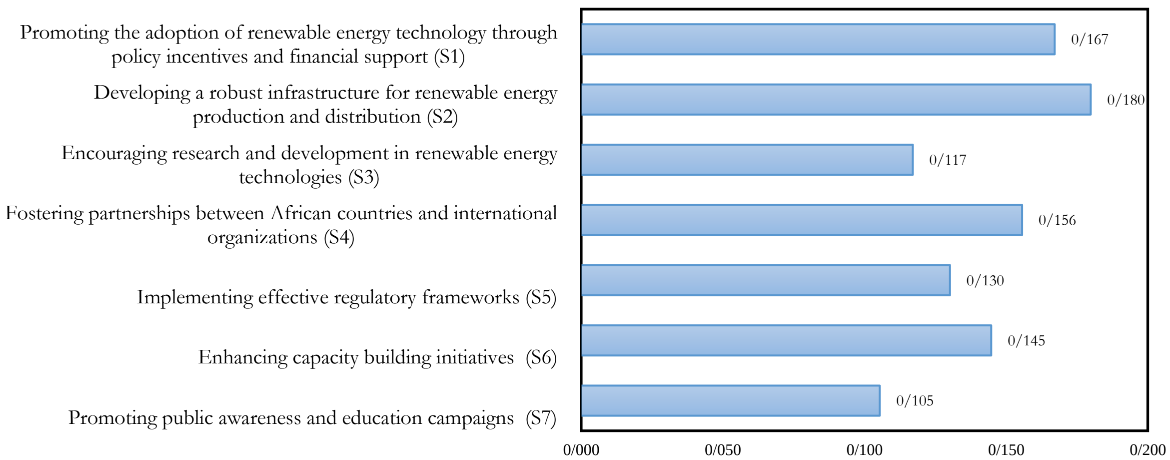

Fig. 2. Criteria weights.

Fig. 2 shows that experts ranked developing robust infrastructure for RE (S2) as the top strategy, followed by promoting its adoption through policy incentives and financial support (S1) and fostering partnerships (S4). Other strategies are ranked as follows: S6 > S5 > S3 > S7.

5 | Comparative Analysis

Comparative analyses are used to assess criteria weighting from the IVIF-SWARA method against BWM and AHP. AHP relies on expert pairwise comparisons to determine criterion importance, while BWM uses Best-Worst comparisons when objective data is lacking. The IVIF-SWARA approach improves decision-making by handling complexity and imprecise information. The results for each method are shown in *Fig. 3*.

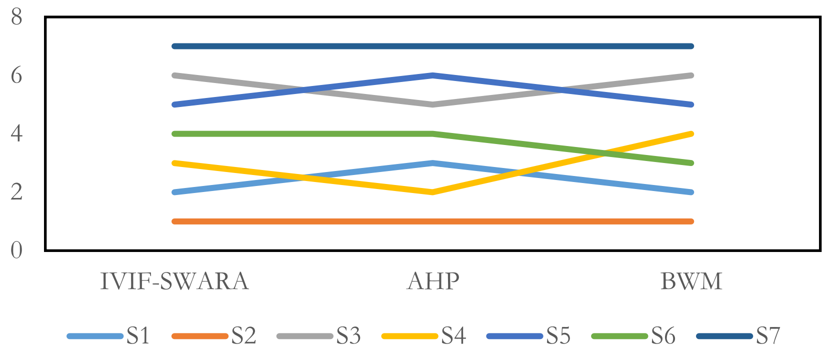

Fig. 3. Comparative analysis results.

As shown in *Fig. 3*, strategies S2 (best) and S7 (worst) consistently hold the same ranking across all methods. Strategies S1, S5, and S3 retain their second, fifth, and sixth positions with the IVIF-SWARA and BWM methods but shift to third, sixth, and fifth places with the AHP approach. Strategy S6, ranked fourth by both IVIF-SWARA and AHP, moves to third place with BWM. Meanwhile, strategy S4, ranked third by IVIF-SWARA, is placed second by AHP and fourth by BWM. Discrepancies between these results during comparative analysis arise from differences in their underlying frameworks and computational processes. The IVIF- SWARA method incorporates uncertainty by allowing decision-makers to express both membership and non-membership values with ranges, capturing a higher degree of hesitancy and imprecision.

In contrast, BWM simplifies weighting by focusing on pairwise comparisons between the "best" and "worst" criteria, offering a more direct but less flexible approach. AHP, meanwhile, uses full pairwise comparisons to determine criteria weights, which can be more comprehensive but prone to inconsistencies. Furthermore, the methods differ in their aggregation processes: SWARA ranks criteria stepwise, while BWM compares only the best and worst, and AHP evaluates all criteria pairwise. The way each method handles preference elicitation also varies, with AHP requiring comprehensive comparisons that may introduce inconsistency, BWM simplifying the process, and SWARA allowing for more nuanced judgments through interval values. These differences in handling uncertainty, weighting mechanisms, and aggregation lead to variations in the results across the methods, making comparative analyses challenging but also highlighting each method's unique strengths and limitations in decision-making.

6 | Findings and Discussion

Drawing on past research and expert views, the IVIF-SWARA method was used to identify the most effective innovative technology dissemination strategies for GHG reduction in Africa.

Our research highlights that the most appropriate strategy is to build a strong infrastructure for RE production and distribution (S2). This finding aligns with the study by Nwokolo et al. [10], which highlights the significance of utilizing Africa's abundant natural resources, especially solar and wind power, to address barriers to technological diffusion. They argue that substantial investment in solar farms, wind turbines, and other RE infrastructure will not only help African nations meet their growing energy demands but also significantly reduce GHG emissions. Such efforts would contribute to the fight against climate change while simultaneously promoting economic growth, generating employment opportunities, and improving public health by decreasing dependence on fossil fuels. Furthermore, strengthening RE infrastructure would attract

foreign direct investment, stimulate technological advancements, and enhance energy security, making African countries more resilient to external energy shocks. In the long term, this strategy could position Africa as a global leader in the transition to sustainable energy systems, helping to foster regional integration and economic independence while setting a precedent for other developing regions to follow. These broader impacts, including job creation, improved public health, and greater energy security, highlight the multifaceted benefits of investing in RE infrastructure, not only for environmental sustainability but also for socio-economic development.

Encouraging RE adoption through policy incentives and financial support (S1) emerges as the second most effective strategy. According to the study conducted by Ozoegwu and Akpan [72] in Nigeria, policy measures such as subsidies, tax breaks, and favorable regulations are crucial in creating a conducive investment environment that attracts both local and international investors to the RE sector. These incentives reduce the financial barriers to entry, making RET more affordable and accessible while also providing long-term economic benefits. By accelerating the adoption of RETs, such policies promote technological innovation, driving down costs through economies of scale and increasing the competitiveness of RE in the energy market. Ozoegwu and Akpan [72] argue that African governments should prioritize the development of RE by implementing supportive and stable policy frameworks. These frameworks would encourage private sector participation, reduce dependency on fossil fuels, and align with global efforts to combat climate change. Moreover, by incentivizing RE development, governments can help spur economic growth, create new job opportunities, and improve energy access for underserved populations. This shift towards RE would not only help meet national and regional energy needs but also contribute to a more sustainable and resilient energy future. In the long term, such policies could position African countries as leaders in clean energy adoption while reducing their carbon footprint and ensuring energy security. By fostering a supportive policy environment, African nations would be better equipped to transition to a low-carbon economy, protect the environment, and enhance the well-being of their populations through cleaner, more reliable energy sources.

Fostering partnerships (S4) is a third significant strategy, as Nwokolo et al. [10] indicated in their Africa-related study. They emphasize that governments should establish a comprehensive policy framework designed to encourage collaboration across multiple sectors and stakeholders. Such frameworks could include the creation of dialogue platforms to facilitate communication between governments, private enterprises, and research institutions. These platforms would help bridge gaps between different sectors, promote knowledge sharing, and foster innovative solutions to overcome existing challenges in RE adoption. In addition, governments should support joint projects between local and international partners, offering funding and resources to drive collaborative initiatives aimed at RET capacity-building and R&D. African governments are also encouraged to actively participate in international conferences, forums, and summits that focus on energy, climate change, and sustainable development. Engaging in such events would enable African countries to form cross-border partnerships, enhance networking opportunities, and leverage global expertise and technological advancements. By forging stronger ties with global organizations, African nations can benefit from knowledge exchange and access to critical resources, such as funding, technological innovation, and best practices for RE deployment. Moreover, through active participation in international dialogues, African countries have the opportunity to influence and shape global policies and priorities that directly impact their energy needs and development goals. This involvement ensures that Africa's unique challenges and opportunities are adequately addressed in global decision-making processes, helping to promote equitable solutions for the continent. Strengthening these international collaborations can also lead to better coordination on issues like climate finance, infrastructure development, and the transfer of clean energy technologies, all of which are essential for achieving sustainable development. Additionally, partnerships with global institutions can open doors to new markets, improve regional energy integration, and facilitate long-term investments in RE infrastructure, further boosting Africa's capacity to transition to a low-carbon future while promoting economic growth and energy security.

Enhancing capacity-building initiatives (S6) is a key strategy for reducing GHG emissions. A well-developed capacity-building program ensures that the workforce is adequately trained and equipped with the necessary

skills to support the growing demands of the RE industry. To achieve this, governments should promote vocational training programs focused on RETs and foster partnerships with educational institutions by providing subsidies and financial incentives for RE-specialized training. By investing in education and skill development, governments can secure a steady supply of proficient workers capable of operating, maintaining, and innovating within the sector. This would not only boost the immediate labor market but also create a foundation for long-term sustainability in the industry.

Additionally, these initiatives must be designed to address the dynamic nature of the RE landscape, ensuring that training programs evolve alongside technological advancements. Collaboration with industry experts is essential to keep vocational training and academic curricula relevant and aligned with current industry demands. This can be achieved by involving key stakeholders from both the public and private sectors, including manufacturers, project developers, and utility companies, in the design and implementation of training programs. By doing so, governments can ensure that the workforce remains adaptable and skilled in the latest RETs and practices, including the installation and maintenance of solar panels, wind turbines, and other RE systems. Furthermore, capacity-building initiatives can play a significant role in driving innovation by encouraging R&D in collaboration with academic institutions and industry leaders. This approach not only enhances the skillset of workers but also stimulates technological advancements and improvements in energy efficiency, which are critical for reducing GHG emissions.

7 | Managerial Implications

This study provides key insights for African governments looking to cut carbon emissions through innovative technology. It outlines four strategies: developing RE infrastructure, using policy incentives to boost adoption, fostering partnerships, and enhancing capacity-building. These approaches are vital for addressing climate change and advancing sustainable development in Africa. The study offers practical recommendations, emphasizing the need to invest in solar farms and wind turbines to help African countries address their energy needs and reduce GHG emissions. It also suggests providing subsidies and tax incentives to create a favorable investment environment that attracts both local and international investors. Additionally, establishing a solid policy framework to promote collaboration, including creating dialogue platforms and supporting joint projects, is crucial. Governments should also focus on enhancing vocational training and forming partnerships with educational institutions to ensure a reliable supply of skilled workers and support long-term sustainability.

8 | Conclusion

This study explores the use of the IVIF-SWARA technique to transform Africa's carbon footprint through innovative technology strategies for reducing GHG emissions, providing valuable guidance for African governments. By incorporating expert opinions, it evaluates these strategies and establishes a critical basis for informed decision-making. Through an African case study, the research highlights the technique's effectiveness in pinpointing key strategies. The study highlights four key strategies: building strong RE infrastructure, promoting adoption through incentives and support, fostering international partnerships for knowledge sharing, and enhancing capacity-building efforts. While our research offers valuable insights, it has some limitations. Firstly, it was carried out at a continental scale, which does not address the diversity among African countries and regions. Future studies should explore regional or country-specific analyses for a more detailed understanding. Secondly, the study relied on input from a small number of experts. Future research should expand this to include a broader range of experts and develop a consensus-based model with a consensus coefficient for more robust findings. Lastly, in addition to utilizing a possibilistic programming framework under uncertainty [73], future decision-making models could benefit from an advanced algorithm [74] and the double normalization method [75]. These approaches are highly recommended for enhancing the accuracy and effectiveness of decision-making processes. Furthermore, future research should explore the application of these methodologies in evaluating sustainability initiatives, achieving decarbonization in the

transportation sector, and implementing circular economy practices. These areas present valuable opportunities for further development and practical use of the proposed framework.

Author Contributaion

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Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflict of interest.

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Appendix A

Table A1. Linguistic expressions of the criteria.

Linguistic Term	IVIF Scale
Absolutely low (AL)	([0.10, 0.25], [065, 0.75])
Very low-VL	([0.15, 0.30], [0.60, 0.70])
Low-L	([0.20, 0.35], [0.55, 0.65])
Medium low-ML	([0.25, 0.40], [0.50, 0.60])
Medium-M	([0.50, 0.50], [0.50, 0.50])
Medium high-MH	([0.50, 0.60], [0.25, 0.40])
High-H	([0.55, 0.65], [0.20, 0.35])
Very high-VH	([0.60, 0.70], [0.15, 0.30])
Absolutely high-AH	([0.65, 0.75], [0.10, 0.25])

Table A2. Background of experts.

Experts	Occupation	Experience	Gender	Degree
E_1	Academia	20	Male	Ph.D.
E_2	Academia	17	Male	M.Sc.
E_3	Industry	12	Female	M.Sc.
E_4	Industry	10	Female	B.Sc.

Table A3. Strategies to reduce GHGs emissions in Africa.

Strategies	References
Promoting the adoption of renewable energy technology through policy incentives and financial support (S1)	[71]
Developing a robust infrastructure for renewable energy production and distribution (S2)	[71]
Encouraging research and development in renewable energy technologies to drive innovation (S3)	[71]
Fostering partnerships between African countries and international organizations to share knowledge and resources (S4)	[12]
Implementing effective regulatory frameworks to ensure the smooth integration of renewable energy into existing power systems (S5)	[71]
Enhancing capacity building initiatives to train a skilled workforce in the renewable energy sector (S6)	[71]
Promoting public awareness and education campaigns to increase understanding and support for renewable energy adoption (S7)	[4]